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[54] **SYSTEM AND METHOD FOR DETECTING ATRIAL EVENTS OF A HEART**

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[57] **ABSTRACT**

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A continuous monitoring system monitors atrial activity of a heart and activates an atrial fibrillation detector when atrial fibrillation is suspected. The system includes an A wave detector for detecting A waves of the heart and providing an A wave detection signal indicating each detected A wave. The A wave detector has a first threshold and a selectable second threshold higher than the first threshold. An R wave detector for detecting R waves of the heart is coupled to the A wave detector for selecting the second threshold of the A wave detector during each detected R wave of the heart. An atrial cycle length determining stage determines atrial cycle lengths from the A wave detection signal and a comparator activates atrial fibrillation detection when an atrial cycle length is shorter than a predetermined cycle length.

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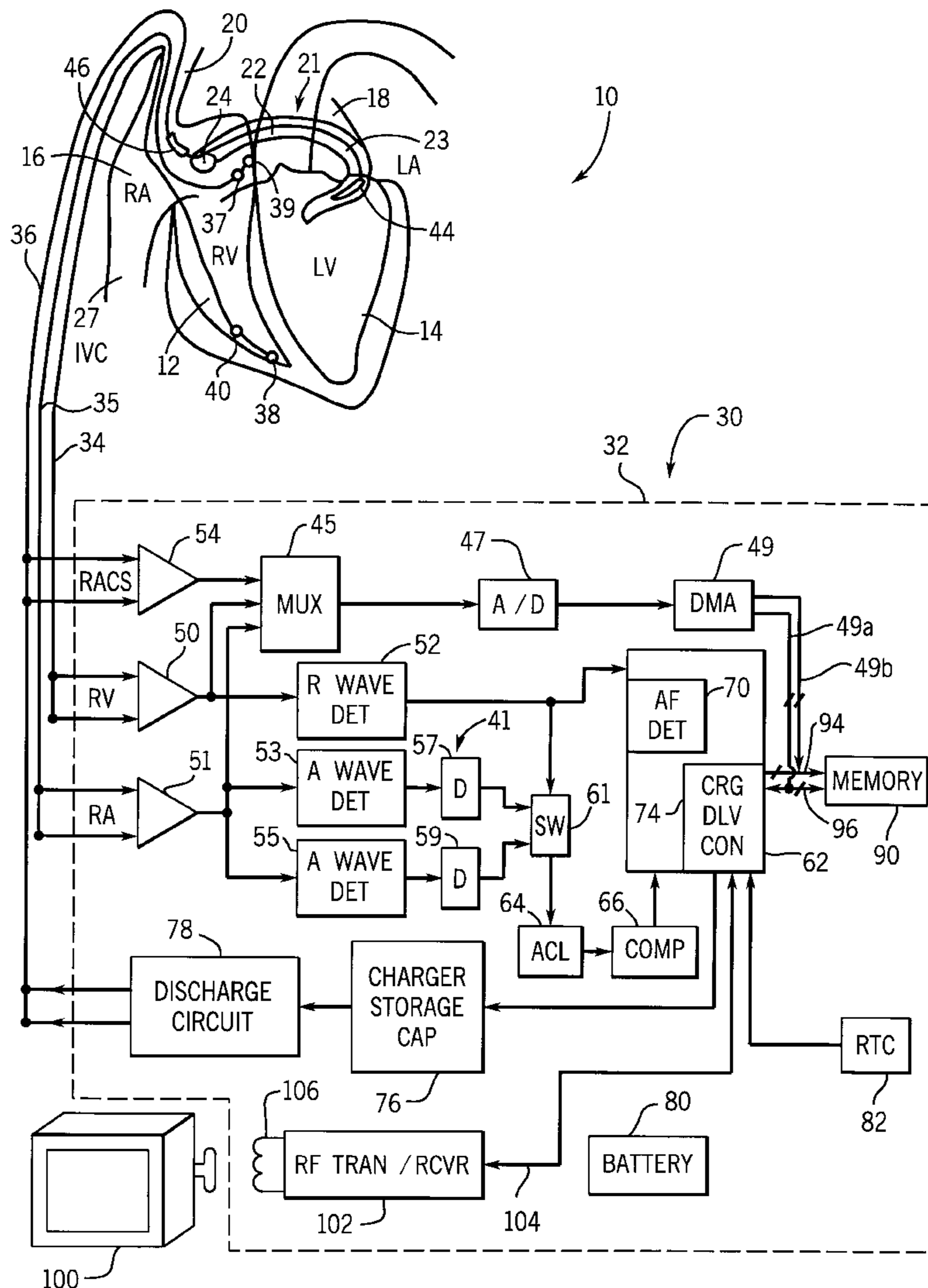
[58] Field of Search 607/4, 5; 600/515, 600/518, 521

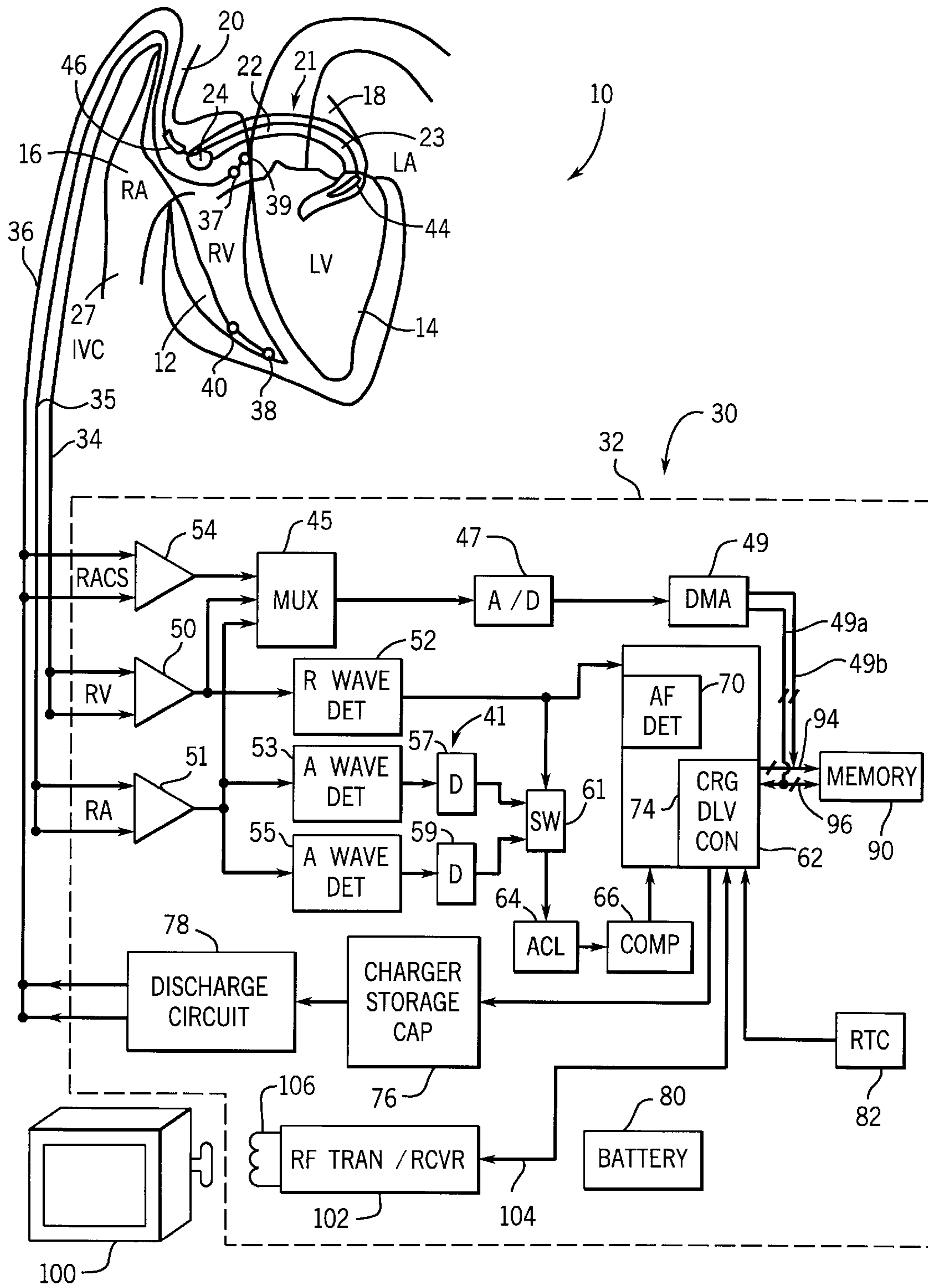
[56] References Cited

U.S. PATENT DOCUMENTS

- 5,267,559 12/1993 Jin et al. 607/5
- 5,685,315 11/1997 McClure et al. 600/521

9 Claims, 1 Drawing Sheet





SYSTEM AND METHOD FOR DETECTING ATRIAL EVENTS OF A HEART

BACKGROUND OF THE INVENTION

The present invention generally relates to a method and system for detecting atrial events of a heart. The present invention is more particularly directed to such a system and method which detects A waves of a heart in the presence of ventricular activity wherein A waves are normally detected with a first threshold but, during detected ventricular activity the threshold is raised to a second threshold, higher than the first threshold to avoid sensing ventricular activity as atrial activity.

Atrial fibrillation is probably the most common cardiac arrhythmia. Although it is not usually a life-threatening arrhythmia, it is associated with strokes thought to be caused by blood clots forming in areas of stagnant blood flow as a result of prolonged atrial fibrillation. In addition, patients afflicted with atrial fibrillation generally experience rapid and irregular beating of the heart and may even experience dizziness as a result of reduced cardiac output.

Atrial fibrillation occurs suddenly, and many times can only be corrected by discharging electrical energy into the atria of the heart of the patient. This treatment is preferably synchronized to a detected R wave of the heart in order to avoid shocking the atria during the T wave or vulnerable period of the heart. The amount of energy which may be required to successfully cardiovert the atria can be as low as one joule and as high as six joules. In most cases, energy of about two to four joules is required to cardiovert atrial fibrillation back to normal sinus rhythm (NSR).

Implantable atrial defibrillators are known which detect the presence of atrial fibrillation and provide a single cardioverting pulse of electrical energy to the atria when atrial fibrillation is detected. Usually, the therapy is applied in synchrony with a detected R wave to avoid therapy application during the ventricular vulnerable period of the heart thereby preventing the induction of a lethal ventricular arrhythmia.

Atrial fibrillation detection may be initiated at spaced apart times with such devices to conserve battery power as disclosed, for example, in U.S. Pat. No. 5,464,432. Alternatively, such devices may provide continuous monitoring of heart activity to activate more specific atrial fibrillation detections when the monitored activity indicates a probability of atrial fibrillation.

One such atrial defibrillator is disclosed in U.S. Pat. No. 5,282,837. As disclosed in that patent, ventricular activity is continuously monitored. When the ventricular rate and/or ventricular rate variability reach a certain level, atrial fibrillation is suspected and a more robust and higher battery energy consumption algorithm for atrial fibrillation detection is initiated and implemented with a microprocessor.

Continuous monitoring of ventricular activity to predict when atrial fibrillation may be present may be effective for many patients. However, for patients with heart block, ventricular sensing may not be as effective as would be desirable. The reason for this is that when a patient has heart block, ventricular activity is generally not associated with or related to atrial activity. Hence, ventricular activity may not provide the best indication of possible atrial fibrillation.

In view of the foregoing, it would be desirable to be able to continuously monitor atrial activity for identifying possible atrial fibrillation. Such monitoring, would be effective for all patients, including heart block patients. However,

atrial sensing for purely atrial events can be complicated by the presence of other heart activity, such as ventricular activity. Far field sensing of ventricular activations (R waves) could be mistaken for atrial activity resulting in false indications of possible atrial fibrillation. The present invention provides a system and method of detecting atrial events which avoids detection of R waves as atrial events to result in accurate predictions of possible atrial fibrillation.

SUMMARY OF THE INVENTION

The invention provides a system for detecting atrial events of a heart including A wave detecting means for detecting A waves of the heart and providing an A wave detection signal indicating each detected A wave. The A wave detecting means includes a first threshold and a second threshold higher than the first threshold. The system further includes an R wave detector for detecting R waves of the heart and which is coupled to the A wave detecting means for activating the second threshold of the A wave detecting means during each detected R wave of the heart.

The invention further provides a system for detecting atrial events of a heart including a first sense amplifier for sensing atrial activity of a heart and a second sense amplifier for sensing ventricular activity of the heart. The system further includes A wave detecting means coupled to the first sense amplifier for providing an output signal indicating each detected A wave. The A wave detecting means has a first threshold and a second threshold higher than the first threshold. An R wave detector is coupled to the second sense amplifier for detecting R waves from the sensed ventricular activity. Delay means causes a delay in the output signal and switch means coupled to the R wave detector switch the A wave detecting means from the first threshold to the second threshold during each detected R wave.

The present invention still further provides a continuous monitoring system for monitoring atrial activity of a heart and activating atrial fibrillation detection when atrial fibrillation is suspected. The system includes A wave detecting means for detecting A waves of the heart and providing an A wave detection signal indicating each detected A wave wherein the A wave detecting means includes a first threshold and a second threshold higher than the first threshold. The system further includes an R wave detector for detecting R waves of the heart and coupled to the A wave detecting means for activating the second threshold of the A wave detecting means during each detected R wave of the heart; means for determining an atrial cycle length from the A wave detection signal, and activation means for activating atrial fibrillation detection responsive to the atrial cycle lengths.

The invention still further provides a method of detecting atrial events of a heart. The method includes the steps of sensing atrial activity of the heart, sensing ventricular activity of the heart, detecting R waves from the sensed ventricular activity, and detecting A waves from the sensed atrial activity with a first threshold and with a second threshold higher than the first threshold during detected R waves.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may best be understood by making reference to the following description taken in conjunction with the accompanying drawing, in the sole FIGURE of which like reference numerals identify identical elements,

and wherein the sole FIGURE is a schematic block diagram of a fully implantable atrial defibrillator embodying the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Prior to referring to FIG. 1, a general description of a typical or normal cardiac cycle may be helpful in understanding the operation and various aspects of the present invention. The beginning of a cardiac cycle in normal sinus rhythm is initiated by a P wave which is normally a small positive wave. The P wave induces depolarization of the atria of the heart. Following the P wave there is a cardiac cycle portion which is substantially constant having a time duration on the order of, for example, 120 milliseconds. As a precaution, and to avoid potential confusion, the term "A wave" shall be used herein to denote atrial activity including P waves satisfying certain amplitude or threshold requirements.

The QRS complex of the cardiac cycle then normally occurs after the substantially constant portion. The dominating feature of the QRS complex is the ventricular activation, or R wave, which is a rapid positive or negative deflection. The R wave generally has an amplitude greater than any other wave of the cardiac cycle and is characterized by a rapid deviation from and return toward baseline. The R wave is the depolarization of the ventricles. The QRS complex is completed by the S wave which is generally a small deflection which returns the cardiac cycle to baseline.

Following the S wave of the QRS complex, the T wave occurs which is separated from the QRS complex by about 250 milliseconds. The T wave is relatively long in duration of, for example, on the order of 150 milliseconds. The cardiac cycle segment between the S wave and the T wave is commonly referred to as the ST segment.

The next cardiac cycle begins with the next P wave. The duration of a cardiac cycle may be on the order of 800 milliseconds.

Referring now to FIG. 1, it illustrates a fully implantable atrial defibrillator 30 embodying the present invention shown in association with a schematically illustrated human heart 10. The portions of the heart 10 illustrated in the sole figure are the right ventricle 12, the left ventricle 14, the right atrium 16, the left atrium 18, the superior vena cava 20, the coronary sinus channel 21 which, as used herein, denotes the coronary sinus 22 and the great cardiac vein 23, the coronary sinus ostium or opening 24, and the inferior vena cava 27.

The atrial defibrillator 30 generally includes an enclosure 32 for hermetically sealing the internal circuit elements of the atrial defibrillator to be described hereinafter, a ventricular endocardial or first lead 34, a right atrial endocardial or second lead 35 and an intravascular or third lead 36. The enclosure 32 and leads 34, 35, and 36 are arranged to be implanted beneath the skin of a patient so as to render the atrial defibrillator 30 fully implantable.

The intravascular lead 36 generally includes a first or tip electrode 44 and a second proximal electrode 46. As illustrated, the lead 36 is flexible and arranged to be passed down the superior vena cava 20, into the right atrium, into the coronary sinus ostium 24, and advanced into the coronary sinus channel 21 of the heart near the left side thereof so that the first or tip electrode 44 is within the coronary sinus channel 21 either within the coronary sinus 22 adjacent the left ventricle 14 and beneath the left atrium 18 or most preferably within the great cardiac vein 23 adjacent the left

ventricle 14 and beneath the left atrium 18. The electrodes 44 and 46 are spaced apart such that when the first electrode 44 is positioned as described above, the second electrode 46 is in the right atrium 16. The first electrode 44 together with the second electrode 46 provide bi-polar sensing of heart activity in the atria 16 and 18. The first electrode 44 and the second electrode 46 further provide for the delivery of defibrillating electrical energy to the atria. The electrodes 44 and 46 are preferably elongated cardioverting electrodes.

The first lead 34 preferably comprises a ventricular endocardial lead having bi-polar pair electrodes 38 and 40 arranged for establishing electrical contact with the right ventricle 12 of the heart 10. The electrodes 38 and 40 permit bi-polar sensing of ventricular activations in the right ventricle and pacing in the right ventricle. As illustrated, the lead 34 is fed through the superior vena cava 20, into the right atrium 16, and then into the right ventricle 12.

The second lead 35 preferably comprises a right atrial endocardial lead having bi-polar pair electrodes 37 and 39. Electrode 39 preferably is a helical screw-in coil for both providing fixation of the lead 35, as known in the art, and establishing electrical contact with the right atrium 16 of the heart 10. The electrodes 37 and 39 permit localized bi-polar sensing of heart activity in the right atrium. As illustrated, the lead 35 is fed through the superior vena cava 20 and into the right atrium 16.

Within the enclosure 32, the atrial defibrillator 30 includes a first sense amplifier 50, a second sense amplifier 51, a third sense amplifier 54 and an R wave detector 52. The first sense amplifier 50 forms an RV channel which provides an electrogram of the sensed right ventricular heart activity at an input of multiplexer 45 and to an input of an R wave detector 52.

The second sense amplifier 51 forms an RA channel to provide an electrogram of the sensed right atrial heart activity at its output which is coupled to an input of multiplexer 45 and to an input of a first A wave detector 53 and an input to a second A wave detector 55. The first and second A wave detectors 53 and 55 are in turn coupled to first and second delay circuits 57 and 59 respectively. The delay circuits 57 and 59 are coupled as inputs to a switch 61. As will be explained subsequently, the A wave detectors 53 and 55, delay circuits 57 and 59, and switch 61 form a system 41 for reliably detecting A waves in accordance with this embodiment of the present invention.

The third sense amplifier 54 forms an RACS channel to provide an electrogram of the sensed right atrium to left atrium heart activity at its output which is coupled to another input of the multiplexer 45. Each of the sense amplifiers 50, 51 and 54 may include a differentiating filter so that the electrograms which they provide are differentiated electrogram signals.

The R wave detector 52 provides one or more output pulses for each R wave sensed during a cardiac cycle of the heart. To that end, the R wave detector may include a further differentiating filter for differentiating the differentiated cardiac signal provided by sense amplifier 50 resulting in a twice differentiated second cardiac signal. The R wave detector 52 may further include a threshold circuit for setting an upper and lower threshold which provides an output when the twice differentiated second cardiac signal transitions beyond either the upper or lower thresholds.

Finally, the R wave detector preferably further includes an output pulse rate limiter (not shown) having a programmable pulse repetition time interval. The pulse repetition time interval is set to be as short as possible to allow detection of

the last threshold crossing for an R wave. The R wave detector **52** thus provides at least one such pulse to indicate the beginning of each detected R wave and one such pulse to indicate the completion of each detected R wave so that the beginning and end of each R wave may be determined. The R wave detector **52** is coupled to the switch **61** for controlling the operation of the switch.

The A wave detectors **53** and **55** also preferably include a similar further differentiating filter (not shown) and output pulse rate limiter (not shown). This similarly enables the A wave detectors to provide at least one output pulse to indicate the beginning of each sensed A wave and another to indicate the end of each sensed A wave.

The enclosure **32** of the atrial defibrillator **30** further includes a microprocessor **62**. The microprocessor **62** is preferably implemented in accordance with this embodiment of the present invention to result in a plurality of functional stages. The stages include an atrial arrhythmia detector in the form of an atrial fibrillation detector **70** and a charge and energy delivery control stage **74**.

The microprocessor **62** is arranged to operate in conjunction with a memory **90** which is coupled to the microprocessor **62** by a multiple-bit address bus **94** and a bi-directional multiple-bit data bus **96**. This permits the microprocessor **62** to address desired memory locations within the memory for executing write or read operations. During a write operation, the microprocessor stores data, such as time stamps, or operating parameters, in the memory at the addresses defined by multiple-bit addresses conveyed over the address bus **94** and conveys the operating parameters and data to the memory **90** over the multiple-bit data bus **96**. During a read operation, the microprocessor **62** obtains data or operating parameters from the memory at the storage locations identified by the multiple-bit addresses provided over the address bus **94** and receives the operating parameters and data from the memory over the bi-directional data bus **96**.

For entering operating parameters into the memory **90**, the microprocessor **62** receives the programmable operating parameters from an external controller **100** which is external to the skin of the patient. The external controller **100** is arranged to communicate with a receiver/transmitter **102** within enclosure **32** which is coupled to the microprocessor **62** over a bi-directional bus **104**. The receiver/transmitter **102** conveys various information which it obtains from the microprocessor **62** to the external controller **100** or receives programming parameters from the external controller **100** which the receiver/transmitter **102** then conveys to the microprocessor **62** for storage in memory **90**.

The receiver/transmitter **102** includes a transmitting coil **106** so that the receiver/transmitter **102** and coil **106** form a communication means. Such communication means are well known in the art and may be utilized as noted above for receiving commands from the external controller **100** and for transmitting data to the external controller **100**. One preferred communication system is disclosed in U.S. Pat. No. 5,342,408 which issued on Aug. 30, 1994 for "Telemetry System for an Implantable Cardiac Device," which patent is assigned to the assignee of the present invention and incorporated herein by reference.

The atrial defibrillator **30** further includes an analog to digital converter **47** and a direct memory access controller (DMA) **49**. The analog to digital converter **47** has an input coupled to the output of the multiplexer **45** for receiving the electrogram signals generated by the sense amplifiers **50**, **51**, and **54**. During a data acquisition, the analog to digital

converter **47** converts the electrogram signals into digital data. The digital data is received by the DMA **49** which conveys the digital data to memory **90** over a data bus **49a** for storage in memory at predetermined locations selected by the DMA **49** over an address bus **49b**. The electrogram signals thus stored in digital form representing activity of the heart are thereafter utilized by the microprocessor to perform various functions. For example, for atrial fibrillation detection, the atrial fibrillation detector **70** utilizes the stored data from the RACS channel for detecting the presence of atrial fibrillation of the heart.

The atrial defibrillator **30** further includes a charger and storage capacitor circuit **76** of the type well known in the art which charges a storage capacitor to a selected peak voltage and a discharge circuit **78** for discharging the storage capacitor within circuit **76** for a predetermined time to provide a controlled discharge output of electrical energy when required to the atria of the heart. To that end, the discharge circuit **78** is coupled to the first electrode **44** and the second electrode **46** of lead **36** for applying the cardioverting or defibrillating electrical energy to the atria. The defibrillator **30** further includes a depletable power source **80**, such as a lithium battery, for providing power to the electrical components of the atrial defibrillator **30**, and a real time clock **82**.

To briefly describe the operation of the atrial defibrillator for cardioverting atrial fibrillation of the heart, when an atrial fibrillation detection is initiated as described subsequently in accordance with the present invention, the sense amplifiers **50** and **54**, the analog to digital converter **47**, the multiplexer **45** and the DMA **49** are enabled. A data acquisition is first performed for a data acquisition period of, for example, eight seconds. During the eight second data acquisition period, the electrogram signals from sense amplifiers **50**, **51**, and **54** are digitized by the analog to digital converter **57** into digital data and the digital data is caused to be stored in the memory **90** by the DMA **49** as previously described.

After the eight second data acquisition period is completed, the atrial fibrillation detector **70** is enabled and analyzes the stored electrogram data from the RACS channel. The atrial fibrillation detector **70** may determine if the atria **16** and **18** are in fibrillation in a manner known in the art as, for example, described in U.S. Pat. No. 5,486,199 which issued on Jan. 13, 1996 for "System and Method For Reducing False Positives In Atrial Fibrillation Detection," which patent is assigned to the assignee of the present invention and incorporated herein by reference. If the atria are in fibrillation and thus in need of cardioversion, the charge delivery control **74** causes the charger and storage capacitor circuit **76** to charge the storage capacitor within the circuit **76** to a selected peak voltage. After the capacitor is charged, another data acquisition is performed and the atrial fibrillation detector **70** confirms the presence of atrial fibrillation. Thereafter, and in timed relation to a detected R wave, the discharge circuit **78**, applies a portion of the stored electrical energy to electrodes **44** and **46** and thus the atria **16** and **18** to cardiovert the atria **16** and **18**.

In accordance with a preferred embodiment of the present invention, an atrial fibrillation detection is initiated by the A wave detection system **41**, an atrial cycle length (ACL) determining stage **64** and a comparator **66**. The sense amplifier **51** continuously monitors and senses activity of the heart from the electrode pair **37**, **39** in the right atrium. It thereby provides an atrial electrogram to the A wave detectors **53** and **55**.

The first and second A wave detectors **53** and **55** are preferably identical except that the second A wave detector

55 has a threshold which is higher than the threshold of the first A wave detector **53**. Hence, a higher amplitude electrogram signal is required to cause an A wave detection output from the second A wave detector **55** than is required to cause an A wave detection output from the first A wave detector **53**. As will be seen hereinafter, A wave detection is normally performed by the first A wave detector **53** having the lower threshold.

The switch **61** switches between the delay circuits **57** and **59**. Normally, switch **61** receives A wave detection outputs from the delay circuit **57**.

The ACL stage **64** computes atrial cycle lengths, in a continuous manner, from the A wave detection output received from the switch **61**. It provides the atrial cycle lengths to the comparator **66** which compares the computed atrial cycle lengths to a predetermined limit, such as 200 milliseconds, for example. When an atrial cycle length falls below the predetermined limit, the comparator activates or wakes up the microprocessor **62** to initiate an atrial fibrillation detection.

To avoid mistaking a far field sensed R wave for an A wave, during each detected R wave, the switch selects delay circuit **59**. This causes the higher threshold of A wave detector **55** to be used for detecting A waves. Since far field sensed R waves should be lower in amplitude than actual A waves as sensed by electrodes **37** and **38**, raising the detection threshold during R waves causes far field sensed R waves to be undetected. When each R wave is completed, the switch returns to select delay circuit **57**. In this way, A wave detection is normally performed using the lower detection threshold of A wave detector **53** and with maximum sensitivity.

Because the RA sense amplifier **51** may sense an R wave before the RV sense amplifier **50**, the delay circuits **57** and **59** are provided to introduce a short delay in the atrial detection signals. Because there is no delay in the electrogram from the RV sense amplifier **50** or detected R waves from R wave detector **52** to the switch **61**, it will be assured that the A wave detection threshold will be raised before an R wave has an opportunity of being considered an A wave.

As those skilled in the art will appreciate, the delay may alternatively be introduced at the output of sense amplifier **51**. Further, if the delay were introduced in this alternative manner, a single A wave detector having selective lower and higher thresholds may be employed with the threshold selection being performed by the R wave detector as described.

While particular embodiments of the present invention have been shown and described, modifications may be made, and it is therefore intended in the appended claims to cover all such changes and modifications which fall within the true spirit and scope of the invention.

What is claimed is:

1. A system for detecting atrial events of a heart comprising:

A wave detecting means for detecting A waves of the heart and providing an A wave detection signal indicating each detected A wave, the A wave detecting means including a first threshold and means for providing the A wave detection signal when an A wave is detected with the first threshold and a second threshold higher than the first threshold and means for providing the A wave detection signal when an A wave is detected with the second threshold; and

an R wave detector for detecting R waves of the heart and coupled to the A wave detecting means for activating

the second threshold of the A wave detecting means during each detected R wave of the heart.

2. A system as defined in claim **1** further including delay means for delaying the A wave detection signal.

3. A system as defined in claim **1** wherein the system further includes an atrial sense amplifier for sensing atrial activity of the heart and providing an electrogram signal and wherein the A wave detecting means include first and second A wave detectors each having an output and an input coupled to the atrial sense amplifier for receiving the electrogram signal, first and second delay circuits each having an output and an input coupled to the first and second A wave detector outputs respectively, a switch having an output for providing the A wave detection signal and being selectively coupled to the first and second delay circuit outputs responsive to the R wave detector.

4. A system for detecting atrial events of a heart comprising:

a first sense amplifier for sensing atrial activity of a heart;
a second sense amplifier for sensing ventricular activity of the heart;

A wave detecting means coupled to the first sense amplifier for providing an output signal indicating each detected A wave, said A wave detecting means having a first threshold and means for providing the output signal when an A wave is detected with the first threshold and a second threshold higher than the first threshold and means for providing the output signal when an A wave is detected with the second threshold;

an R wave detector coupled to the second sense amplifier for detecting R waves from the sensed ventricular activity;

delay means for causing a delay in the output signal; and
switch means coupled to the R wave detector for switching the A wave detecting means from the first threshold to the second threshold during each detected R wave.

5. A continuous monitoring system for monitoring atrial activity of a heart and activating atrial fibrillation detection when atrial fibrillation is suspected, the system comprising:

A wave detecting means for detecting A waves of the heart and providing an A wave detection signal indicating each detected A wave, the A wave detecting means including a first threshold and means for providing the A wave detection signal when an A wave is detected with the first threshold and a second threshold higher than the first threshold and means for providing the A wave detection signal when an A wave is detected with the second threshold;

an R wave detector for detecting R waves of the heart and coupled to the A wave detecting means for activating the second threshold of the A wave detecting means during each detected R wave of the heart;

means for determining an atrial cycle length from the A wave detection signal; and

activation means for activating atrial fibrillation detection responsive to the atrial cycle lengths.

6. A system as defined in claim **5** further including delay means for delaying the A wave detection signal.

7. A system as defined in claim **5** wherein the activation means comprises a comparator.

8. A system as defined in claim **5** wherein the system further includes an atrial sense amplifier for sensing atrial activity of the heart and providing an electrogram signal and wherein the A wave detecting means includes first and second A wave detectors each having an output and an input

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coupled to the atrial sense amplifier for receiving the electrogram signal, first and second delay circuits each having an output and an input coupled to the first and second A wave detector outputs respectively, a switch having an output for providing the A wave detection signal and being selectively coupled to the first and second delay circuit outputs responsive to the R wave detector.

9. A method of detecting atrial events of a heart, the method including the steps of:

sensing atrial activity of the heart;

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sensing ventricular activity of the heart;

detecting R waves from the sensed ventricular activity; and

detecting A waves from the sensed atrial activity with a first threshold and detecting A waves from the sensed atrial activity with a second threshold higher than the first threshold during detected R waves.

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